Amendments To The Claims

This listing of claims will replace all prior versions, and listings of claims in the application.

---

1. (original) An angle rotator for rotating an input complex number to produce a rotated complex number according to an input angle θ, said angle rotator comprising:

a memory that stores a sin θ_M value and a cos θ_M value, wherein θ_M is a coarse approximation to said input angle θ;

a first digital circuit that performs a coarse rotation on said input complex number based on said sin θ_M value and said cos θ_M value, resulting in an intermediate complex number;

a fine adjustment circuit that generates a fine adjustment value based on a θ_L value, wherein $\theta_L = \theta - \theta_M$; and

a second digital circuit that performs a fine rotation on said intermediate complex number based on said fine adjustment value, resulting in the rotated complex number.

2. (currently amended) The angle rotator of claim 1, wherein said fine adjustment value is $(1 - \theta_L^2/2)$ <u>and wherein this fine adjustment value is produced by either a two's complement negation of $\theta_L^2/2$ or a one's complement negation of $\theta_L^2/2$</u>.

3. (original) The angle rotator of claim 1, wherein said first digital circuit is a butterfly circuit having a plurality of multipliers that multiply said input complex number by said sin θ_M value and said cos θ_M value.

4. (original) The angle rotator of claim 1, wherein said second digital circuit is a butterfly circuit having a plurality of multipliers that multiply said intermediate complex number by said fine adjustment value.

Claims 5-7 cancelled.

8. (original) The angle rotator of claim 1, wherein said ROM is indexed by θ_M.

a1

9. (original) An angle rotator for rotating an input complex number to produce a rotated complex number according to an input angle θ, said angle rotator comprising:

a memory that stores one or more values that are indexed by a most significant word (MSW) of said input angle, including a first value that is an approximation of a sin θ_M value, and a second value that is an approximation of a cos θ_M value, wherein θ_M is a radian angle that corresponds to said MSW of the input angle, and

one or more error values that represent one or more quantization errors associated with at least one of said first value and said second value;

a first digital circuit that performs a coarse rotation on said input complex number based on said first value and said second value, resulting in an intermediate complex number; and

a second digital circuit that performs a fine rotation on said intermediate complex number based on said one or more error values, resulting in the rotated complex number.

10. (original) The angle rotator of claim 9, wherein said first digital circuit is a butterfly circuit.

11. (original) The angle rotator of claim 10, wherein said butterfly circuit includes a plurality of multipliers that multiply said input complex number by said first value and said second value.

12. (currently amended) The angle rotator of claim [9] 13, wherein said ~~one or more~~ quantization ~~errors reflect~~ error reflects a finite memory storage for said first value ~~and second values~~.

13. (original) The angle rotator of claim 9, wherein said first value includes a memory quantization error relative to said sin θ_M value.

14. (currently amended) The angle rotator of claim 9, wherein said first value is [an] a binary n-bit approximation of said sin θ_M value, wherein n is a bit storage capacity for said first value in said memory.

15. (original) The angle rotator of claim 14, wherein said bit storage capacity is N/3 + 1 bits, wherein N is a number of bits that represent a real part of said input complex number.

16. (original) The angle rotator of claim 9, wherein θ_l is an arcsin of said first value, and wherein said one or more error values include:

a first error value that is a difference between said second value and said cos θ_l.

a1

17. (original) The angle rotator of claim 16, wherein said first $\delta_{[\cos\theta_l]}$ error value is represented by as defined by the following equation:

$$\frac{1}{\sqrt{[\cos\theta_l]^2 + (\sin\theta_l)^2}} = 1 + \delta_{[\cos\theta_l]}.$$

18. (currently amended) The angle rotator of claim [9]16, wherein θ_l is an arcsin of said first value, wherein said one or more error values include a second error value that represents (θ_M - θ_m), wherein θ_m = arctan (sin θ_l/ second value).

19. (original) The angle rotator of claim 18, further comprising an adder that adds said second error value to θ_L to produce a θ_l value, wherein θ_L is a radian angle associated with a least significant word (LSW) of said input angle.

20. (original) The angle rotator of claim 19, wherein said angle rotator further comprises a fine adjustment circuit coupled to said second digital circuit, wherein said fine adjustment circuit generates a fine adjustment value based on θ_l and said first error value.

21. (original) The angle rotator of claim 20, wherein said fine adjustment value controls said fine angle rotation in said second digital circuit.

22. (currently amended) The angle rotator of claim 20, wherein said fine adjustment value is approximately: first error value [-] minus ($\frac{1}{2} \cdot \theta_l^2$).

23. (original) The angle rotator of claim 20, wherein said second digital circuit includes a plurality of multipliers.

24. (original) The angle rotator of claim 23, wherein said plurality of multipliers multiply said intermediate complex number by said θ_l value.

25. (original) The angle rotator of claim 23, wherein said plurality of multipliers multiply said intermediate complex number by said fine adjustment value.

26. (currently amended) An angle rotator for rotating an input complex number to produce a rotated complex number according to an input angle, said angle rotator comprising:

a memory that stores one or more values indexed by a most significant word (MSW) of said input angle, including

a first value that is an approximation of a tan θ_M value, and a second value that is an approximation of a cos θ_M value, wherein θ_M is a radian angle that corresponds to said MSW of the input angle, and

a1

one or more error values that represent one or more quantization errors associated with at least one of said first value and said second value;

a first digital circuit that rotates said input complex number based on said ~~tan θ_m~~ first value, resulting in an intermediate complex number; and

a second digital circuit that rotates said intermediate complex number so as to produce at least one part of the rotated complex number, based on said one or more error values and said second value, resulting in the rotated complex number.

27. (currently amended) The angle rotator of claim 26, wherein θ_m is an arctan of said first value, wherein said one or more error values include a first error value associated with a value of: ~~that represents~~ cos θ_m [-] minus said second value.

28. (currently amended) The angle rotator of claim 27~~26~~, wherein θ_m is an arctan of said first value, wherein said one or more error values include a second error value that represents $\theta_M - \theta_m$.

29. (original) The angle rotator of claim 28, further comprising an adder that adds said second error value to θ_L to produce a θ_l value, wherein θ_L is a radian angle associated with a least significant word (LSW) of said input angle.

30. (currently amended) The angle rotator of claim 29, wherein said angle rotator further comprises a fine adjustment circuit coupled to said second digital circuit, wherein said fine adjustment circuit generates a fine adjustment value based on θ_l [,] ~~said second value,~~ and said first error value.

31. (original) The angle rotator of claim 30, wherein said fine adjustment value controls said fine angle rotation in said second digital circuit.

32. (original) The angle rotator of claim 30, wherein said second digital circuit includes a plurality of multipliers.

33. (original) The angle rotator of claim 32, wherein said plurality of multipliers multiply said intermediate complex number by said θ_l value.

34. (original) The angle rotator of claim 32, wherein said plurality of multipliers multiply said intermediate complex number by said fine adjustment value.

35. (currently amended) In a digital device, a method of rotating an input complex number according to a representation of an input angle θ, the method comprising the steps of:

(1) receiving the input complex number;

(2) determining a first value that is an approximation of $\sin \theta_M$, and determining a second value that is an approximation of $\cos \theta_M$, wherein θ_M is a radian angle that corresponds to a most significant word (MSW) of the representation of the input angle θ; and

(3) rotating said input complex number in a complex plane based on said first value and said second value to generate a rotated complex number, whereby said rotated complex number is data processed by said digital device.

36. (original) The method of claim 35, wherein said step of determining comprises the step of retrieving said first value and said second value from a memory.

37. (currently amended) The method of claim 35, ~~wherein θ_1 is an arcsin of said first value,~~ further comprising the step of:

(4) determining a first error value that represents a difference between said second value and $\cos \theta_1$, where θ_1 is an arcsin of said first value.

38. (original) The method of claim 37, further comprising the step of:

(5) rotating said rotated complex number in said complex plane to generate a second rotated complex number based on said first error value.

39. (original) The method of claim 37, further comprising the step of:

(5) determining a second error value that represents $(\theta_M - \theta_m)$, wherein θ_m = arctan (first value/second value).

40. (original) The method of claim 39, further comprising the step of:

(6) adding said second error value to a θ_L value to produce a θ_l value, wherein θ_L is a radian angle associated with a least significant word (LSW) of said input angle θ.

41. (original) The method of claim 40, further comprising the step of:

(7) generating a fine adjustment value based on said θ_l value and said first error value.

42. (currently amended) The method of claim 41, wherein said fine adjustment value is approximately:

first error value [-] minus $(\frac{1}{2} \cdot \theta_l^2)$.

43. (original) The method of claim 41, further comprising the step of:

(8) rotating said rotated complex number according to said fine adjustment value and said θ_l value.

44. (original) The method of claim 43, wherein step (8) comprises the steps of:

(a) multiplying said rotated complex number by said fine adjustment value; and

(b) multiplying said rotated complex number by said θ_l value.

45. (currently amended) In a digital device, a method of rotating an input complex number to produce at least one component of a rotated complex number according to an input angle θ, the method comprising the steps of:

(1) receiving the input complex number;

(2) determining a first value that is an approximation of sin θ_M, and determining a second value that is an approximation of cos θ_M, wherein θ_M is a radian angle that corresponds to ~~said~~ a most significant word (MSW) of the ~~normalized~~ input angle θ;

(3) rotating said input complex number in a complex plane based on said first value and said second value to generate an intermediate complex number;

(4) determining one or more error values that represent one or more quantization errors, including the steps of

(a) determining a first error value that represents a difference between said second value and cos θ_l, wherein θ_l is an arcsin of said first value, and

(b) determining a second error value that represents $(\theta_M - \theta_m)$, wherein θ_m = arctan (first value/ second value);

(5) adding said second error value to a θ_L value to produce a θ_l value, wherein θ_L is a radian angle associated with a least significant word (LSW) of said ~~normalized~~ input angle θ;

(6) generating a fine adjustment value based on θ_l and said first error value; and

(7) rotating said intermediate complex number in said complex plane to generate at least one component of the rotated complex number based on said θ_l value and said fine adjustment value, whereby at least one component of the rotated complex number is data processed by the digital device.

46. (new) An angle rotator for rotating an input complex number to produce an output representing a single coordinate of a rotated complex number according to an input angle θ, said angle rotator comprising:

a memory that stores a first value representing tan θ_M and a second value representing an approximation of cos θ_M, wherein θ_M is an approximation of said input angle θ;

a first digital circuit that performs a first rotation on said input complex number based on said first value, resulting in an intermediate complex number;

means for generating a fine adjustment value;

a second digital circuit that performs a second rotation on said intermediate complex number based on said fine adjustment value to produce an output complex number; and

a scaling circuit that scales said output complex number using said second value to generate the single coordinate output.

47. (new) The angle rotator of claim 46, wherein said fine adjustment value is based on a value of θ_ℓ, where $\theta_\ell = \theta - \theta_m$.

48. (new) An angle rotator for a direct digital frequency synthesizer, for rotating a selected point in the complex plane according to an input angle θ to generate an output representing a rotated complex number, said angle rotator comprising:

a memory that stores a value representing $\sin \theta_1$ and a value approximating $\cos \theta_1$, where θ_1 is an approximation of said input angle θ;

a first digital circuit that obtains said value representing $\sin \theta_1$ from said memory using a value θ_M to address said memory, where θ_M is an approximation of said input angle θ;

means for generating a fine adjustment value;

a second digital circuit that performs a rotation of a point in the complex plane whose coordinates are based on $\sin \theta_1$ and said value approximating $\cos \theta_1$ based on said fine adjustment value, to produce the output representing the rotated complex number.

49. (new) The angle rotator of claim 48 wherein said fine adjustment value is based on a θ_ℓ value, wherein $\theta_\ell = \theta - \theta_m$, where $\theta_m = \arctan(\sin \theta_1 \ / \ [\cos \theta_1])$ and $[\cos \theta_1]$ is an approximation of $\cos \theta_1$.

50. (new) An angle rotator for a direct digital frequency synthesizer, for rotating a selected point in the complex plane according to an input angle θ, to generate an output representing a single coordinate of a rotated complex number, said angle rotator comprising:

a memory that stores a value representing $\sin \theta_1$ and a value approximating $\cos \theta_1$, where θ_1 is an approximation of said input angle θ;

a first digital circuit that obtains said value representing $\sin \theta_1$ from said memory using a value based on θ_M to address said memory, where θ_M is an approximation of said input angle θ;

means for generating a fine adjustment value;

a second digital circuit that performs a rotation of a point in the complex plane whose coordinates are $\sin \theta_1$ and said value approximating $\cos \theta_1$, based on said fine adjustment value, to produce one coordinate value of an output complex number; and

a scaling circuit that scales said coordinate value of said output complex number using said value approximating $\cos \theta_1$ to generate the single coordinate output.

51. (new) The angle rotator of claim 50 wherein said fine adjustment value is based on a θ_ℓ value, wherein $\theta_\ell = \theta - \theta_m$, where $\theta_m = \arctan(\sin \theta_1 / [\cos \theta_1])$ and $[\cos \theta_1]$ is said approximation of $\cos \theta_1$.

52. (new) An angle rotator for a direct digital frequency synthesizer, for rotating a selected point in the complex plane according to an input angle θ, to

generate an output representing a single coordinate of a rotated complex number, said angle rotator comprising:

a memory that stores a value representing tan θ_1 and a value approximating cos θ_1, where θ_1 is an approximation of said input angle θ;

a first digital circuit that obtains said value representing tan θ_1 and said value approximating cos θ_1 from said memory using a value representing θ_M to address said memory, where θ_M is an approximation of said input angle θ;

means for generating a fine adjustment value;

a second digital circuit that performs a rotation of the selected point in the complex plane by an angle approximating θ_M, by using on said value representing tan θ_1 and performing a second rotation of the resulting point in the complex plane, based on said fine adjustment value, to produce one coordinate of an output complex number; and

a scaling circuit that scales said output complex number, using said value approximating cos θ_1, to generate the single coordinate output.

53. (new) A digital signal processing circuit for rotating an input complex number to produce a rotated complex number according to an input angle θ, said circuit comprising:

a first digital circuit that generates a normalized input angle from a value representing the input angle θ;

a second digital circuit for stripping a plurality of most significant bits of said representation of the normalized input angle to obtain a temporary angle τ;

determining means for determining, from τ, whether the normalized input angle represents an angle that is in an even or odd quadrant or octant; and

2's complement negate means for selectively negating the bits remaining after said stripping of most significant bits from the normalized input angle by selectively performing a 2's complement negate operation on said remaining bits;

wherein a resulting angle φ is equal to temporary angle τ if said input angle is in an even octant, and said resulting angle φ is equal to the 2's complement negation of temporary angle τ if said input angle is in an odd octant.

54. (new) A method of rotating an input complex number to produce an output representing a single coordinate of a rotated complex number according to an input angle θ, comprising the steps of:

storing in a memory a value representing tan θ_M and a value representing an approximation of cos θ_M, wherein θ_M is an approximation of said input angle θ;

performing a first rotation on said input complex number based on said value representing tan θ_M, resulting in an intermediate complex number;

generating a fine adjustment value;

performing a second rotation on said intermediate complex number based on said fine adjustment value, to produce an output complex number; and

scaling said output complex number, using said approximation of cos θ_M, to generate the single coordinate output.

55. (new) The method of claim 54, wherein said fine adjustment value is based on a value of θ_ℓ, where $\theta_\ell = \theta - \theta_m$.

56. (new) A method for rotating a selected point in the complex plane in a direct digital frequency synthesizer, according to an input angle θ, to generate an output representing a rotated complex number, comprising the steps of:

storing a value representing $\sin \theta_1$ in a memory and a value representing $\cos \theta_1$ in a memory, where θ_1 is an approximation of said input angle θ;

obtaining said value representing $\sin \theta_1$ from said memory using a value θ_M to address said memory, where θ_M is an approximation of said input angle θ;

generating a fine adjustment value;

performing a rotation of a point in the complex plane whose coordinates are $\sin \theta_1$ and said value representing $\cos \theta_1$, based on said fine adjustment value, to produce the output representing the rotated complex number.

57. (new) The method of claim 56 wherein said fine adjustment value is based on a θ_ℓ value, wherein $\theta_\ell = \theta - \theta_m$, where $\theta_m = \arctan(\sin \theta_1 / [\cos \theta_1])$ and $[\cos \theta_1]$ is an approximation of $\cos \theta_1$.

58. (new) A method for rotating a selected point in the complex plane in a direct digital frequency synthesizer, according to an input angle θ, to generate an output representing a single coordinate of a rotated complex number, comprising the steps of:

storing a value representing $\sin \theta_1$ and a value approximating $\cos \theta_1$ in a memory, where θ_1 is an approximation of said input angle θ;

obtaining said value representing sin θ_l from said memory using a value based on θ_M to address said memory, where θ_M is an approximation of said input angle θ;

generating a fine adjustment value;

performing a rotation of a point in the complex plane whose coordinates are sin θ_l and said value approximating cos θ_l, based on said fine adjustment value, to produce one coordinate value of an output complex number; and

scaling said coordinate value of the output complex number to generate the single coordinate output.

59. (new) The method of claim 58 wherein said fine adjustment value is based on a θ_ℓ value, wherein $\theta_\ell = \theta - \theta_m$, where $\theta_m = \arctan(\sin \theta_l / [\cos \theta_l])$ and $[\cos \theta_l]$ is said approximation of cos θ_l.

60. (new) A method for rotating a selected point in the complex plane in a direct digital frequency synthesizer, according to an input angle θ, to generate an output representing a single coordinate of a rotated complex number, comprising the steps of:

storing in a memory a value representing tan θ_l and a value approximating cos θ_l, where θ_l is an approximation of said input angle θ;

obtaining said value representing tan θ_l and said value approximating cos θ_l from said memory using a value representing θ_M to address said memory, where θ_M is an approximation of said input angle θ;

generating a fine adjustment value;

performing a rotation of the selected point in the complex plane by an angle approximating θ_M by using said value representing tan θ_1 and performing a second rotation of the resulting point in the complex plane, based on said fine adjustment value, to produce a value representing one coordinate of an output complex number; and

scaling said value representing one coordinate of said output complex number using said value approximating cos θ_1 to generate the single coordinate output.

61. (new) In a digital circuit, processing digital data, a method for rotating an input complex number to produce a rotated complex number according to an input angle θ, comprising the steps of:

a1

generating a normalized input angle from a value representing the input angle θ;

stripping a plurality of most significant bits of said value representing the normalized input angle to obtain a temporary angle τ;

determining, from τ, whether the normalized input angle represents an angle in an even or odd quadrant or octant; and

selectively performing a 2's complement negate operation on the bits remaining after said stripping of most significant bits from the normalized input angle,

wherein a resulting angle φ is equal to temporary angle τ if said input angle is in an even octant, and said resulting angle φ is equal to the 2's complement negation of temporary angle τ if said input angle is in an odd octant.

62. (new) In a digital circuit, processing digital data, a circuit for selectively calculating a result value ±C equal to the product of a multiplicand A and an N-bit multiplier B represented by a plurality of multiplier bits $b_0 \ldots b_{N-1}$ or the negative of such product, respectively, comprising:

a selective negating circuit with a control input, where said selective negating circuit receives a plurality of said multiplier bits and outputs said plurality of multiplier bits in negated form in response to a first state of said control input and in non-inverted form in response to a second state of said control input;

a plurality of decoding circuits connected to the negating circuit, each decoding circuit receiving said plurality of multiplier bits and producing a partial product output by multiplying the multiplicand by a value based on a Booth algorithm decoding of said multiplier bits; and

summing means connected to said plurality of decoding circuits for summing said partial product outputs of said plurality of decoding circuits to produce a bit sequence representing the result value.

63. (new) The circuit of claim 62, where said control input comprises a negation control bit and said selective negating circuit comprises a circuit for calculating an exclusive-or of each of said multiplier bits with said negation control bit.

64. (new) In a digital circuit, processing digital data, a method of selectively calculating a result value ±C equal to the product of a multiplicand A and

an N-bit multiplier B represented by a plurality of multiplier bits $b_0 \ldots b_{N-1}$ or the negative of such product, respectively, comprising the steps of:

(a) receiving a plurality of said multiplier bits and a control input;

(b) generating an output of said plurality of multiplier bits in inverted form in response to a first state of said control input and in non-inverted form in response to a second state of said control input;

(c) receiving said plurality of multiplier bits in a plurality of decoding circuits and producing a partial product output by multiplying the multiplicand by a value based on a Booth algorithm decoding of said multiplier bits; and

a1

(d) summing said partial product outputs of said plurality of decoding circuits to produce a bit sequence representing the result value.

65. (new) The method of claim 64, wherein step (b) comprises the step of calculating an exclusive-or of each of said multiplier bits with at least one bit of said control input.